Wage divergence and asymmetries in unemployment in a model with biased technical change

Wage Divergence and Asymmetries in Unemployment in a Model with Biased Technical Change*

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Abstract

In this article we present a model with two levels of skills and two classes of goods, one produced with a technology requiring high skills, the other produced with a technology that can be operated by both low and high skilled workers. In this model skill biased technical change causes a drop in the demand for low skilled workers. The model, however, generates two distinct labour market regimes. In one regime we show skill biased technical change causes wage divergence between skilled and unskilled workers. In the alternative regime a reallocation of labour prevents such wage responses. Introducing labour market institutions through a bargaining process endogenises labour supply. This leads to three possible labour market regimes and shows that skill biased technical change always causes wage divergence but wage responses are moderated by higher unemployment of low skilled workers.

Keywords

Skill biased technological change, job competition, wage divergence, low-skilled unemployment.

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1. Introduction

Over the past decade or so, the labour market perspectives for low skilled workers have worsened dramatically throughout the OECD. This problem has been widely recognised and most authors agree that the causes for this deterioration of labour market perspectives are to be found in the changing composition of labour demand. The OECD (1994) formulated the problem as:

> *.... one of the most serious current challenges in the OECD area is the trend shift in the composition of the demand for labour away from unskilled and towards skilled labour.*

Throughout the OECD, however, it is interesting to note the different manifestations of this seemingly common shift in demand.

In Europe the shift in demand leads to a high and more asymmetric unemployment rate for the low skilled and relative wages hardly adjust. Unemployment is high and rising relatively for low-skilled workers in mainland Europe (OECD (1994), Draper and Manders (1997)) as is the duration of their average unemployment spell (Muysken en Ter Weel (1997)). At the same time we find skilled workers in Europe in jobs that do not require their level of skill, the so called skill mismatch. This mismatch has been on the retreat over recent years (CBS (1996)) but low skilled workers do not replace relocating high skilled workers, indicating low skilled jobs do disappear.

In the US and other Anglo-Saxon countries[1], on the contrary, the most dramatic manifestation of the shifting demand is through relative wages. In these countries they show a very strong tendency to diverge (OECD (1994)). Overall unemployment, in contrast to mainland Europe, is at an all time low even though low skilled workers still suffer a much higher unemployment rate relative to their high skilled competitors. Table 1 summarizes the stylized facts described above that form the starting point for our analysis.

Table 1: Stylized Facts

Stylized Facts		
	OECD	
Low Skilled Labour Demand	Strong Decline	
	Mainland Europe	**US/UK**
Relative Wages	Stable	Strong Divergence
Skill Mismatch	Positive and Decreasing	Insignificant
Unemployment Rates	High	Low
Relative Unemployment Rates	Low and Rising	High and Stable

[1] The UK is the best documented example but wage developments in Australia, New Zealand, Canada show similar trends. These countries are referred to as Anglo-Saxon countries.

For explaining these stylized facts we pose two questions. First of all one has to explain what may have caused the demand for low skilled labour to drop so sharply over the eighties throughout the developed world. One would expect to find a common cause, since this drop can be observed in so many countries over the same period. But then the second question immediately follows. How do we explain so wide a range of different responses to this common cause ?

In this paper we will address these issues by presenting a model that shows how biased technical change causes the relative demand for low skilled workers to fall, but also allows for two distinct labour market regimes that determine the response to this drop in relative demand. We show that the decline in demand can cause either strong wage divergence or it causes a chimney effect where high skilled workers are reallocated from low to high skilled jobs, but relative wages remain stable. By introducing wage bargaining we allow for a more sophisticated analysis of the response to common technology shocks. The extended model yields three regimes in which wage divergence is a common feature but it can be traded off against higher and diverging unemployment rates.

Theoretical Background

Two possible reasons for the drop in the demand for low skilled workers have been suggested in the literature. On the one hand there are those that link the shift in demand to shifts in the sectoral composition of the economy and link these shifts to the process of globalization and increasing trade with low wage/low skilled countries. Key references are Leamer (1994,1995), Burtless (1994) and Lawrence and Slaughter (1993). On the other hand there are those that link this demand shift to pervasive changes in production technology often linked to the IT-revolution. Some notable references are Krugman (1995a), Jackman (1995), Howell (1995) and Agenor and Aizenman (1996). The issue remains to be resolved both in theoretical and empirical work on either approach.

From the research available so far we cannot safely disregard either hypothesis and both will probably explain current events in the OECD partially. However, in this paper we concentrate on linking technological change to labour demand in a way that allows us to show a possible source of bias in technical change that may cause the shift in demand. The reason for our choice of focus in addressing this issue is threefold.

First we simply find the idea of biases in technical change intuitively appealing. It seems evident from casual observation that different forms of technical change involve a particular change in the organisation of the productive process. Introducing a new product usually requires the set up of a whole new production line, which requires a skilled labour force that is capable of dealing with the unforseen problems that occur during this phase of introduction and commercialisation of the new product. As the product matures, the firm can develop and introduce an interface that allows less skilled persons to perform the routine elements in the production process and makes the skilled workers more productive.

Secondly the OECD (1994) presents evidence that the importance of trade in explaining the changes in employment are but a fraction of the impact of productivity changes throughout the OECD. In addition Schimmelpfennig (1998), despite his aim to restore the sectoral shift hypothesis, only explains up to 40% of the change in employment patterns for Germany and

attributes the remaining 60% to skill biased technical change.[2] It thus has a profound impact on labour demand in general. Furthermore the relative size of intra OECD trade to trade with non-OECD countries seems to rule out a severe impact of wage competition from low wage countries at the aggregate level.

A final indication for the relative importance of the technical bias hypothesis comes from Feenstra and Hanson (1997) who show there is also evidence of wage divergence in developing countries, which clearly contrasts with the traditional factor price equilisation theorem. Although circumstantial this evidence supports our intuition and justifies our choice of focus.

On the issue of different responses, notably between mainland Europe and the US, a booming literature has developed over the last few years. Many authors have, and justly so, looked at the differences in wage formation and labour market institutions for an explanation (Teulings and Hartog (1998), Davis (1998), Krugman (1995b)) and indeed found that many of the differences in labour market performance can be explained.

Krugman (1995b) was the first to address the issue and in his paper he argues Europe's labour market rigidities imply an adjustment to the shifting demand in unemployment, whereas the flexible labour markets in the US translate this drop in demand into a decline in relative (and even absolute) wages: "Moneyless America, Jobless Europe". Appealing as this story seems, however, it does not explain the facts.

Nickell and Bell (1995) have shown European high unemployment is not explained by a drop in low skilled labour demand. Furthermore data from the OECD (1994) show high absolute unemployment rates but these are not as skill biased as those in the United States as Krugman's analysis would predict. Davis (1998) concludes he can explain the stylized facts above in a model where Europe has a rigid minimum wage and European low skilled unemployment essentially adjusts to equalize traded goods prices. Localized technical change would yield the strongest conclusions but in our view contrast to the similarity in production techniques used in the US and Europe. Furthermore we feel trade in goods cannot explain the economy wide fall in demand that also manifests itself strongly in non traded services.

In this paper we therefore set out to develop a model that provides an alternative and perhaps complementary explanation for the observed differences in labour market responses. This model allows for different labour market regimes that correspond to the stylized facts independent of labour market institutions. Introducing differences in labour market institutions then strengthens our conclusions.

Outline

Section 2 introduces the model in which we assume two levels of skill and two classes of goods, one produced with a highly sophisticated technology requiring high skills, the other produced with a relatively simple technology that can be operated by both low and high skilled workers. Thus an asymmetry in employment opportunities is assumed.

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[2] Schimelpfennig reclassifies his data in such a way that much of what we would consider technical change shows up as sectoral shifts. He considers the new occupations that emerge and require high skilled workers as a symptom of sectoral shifts. Traditional classifications reduce the explanatory power of the sectoral shift hypothesis to less than a third. Schimmelpfennig (1998) provides a brief summary of the empirical literature on this issue.

Technical change can be introduced in the model by allowing the number of either class of goods to increase over time. The development of new products, labelled *product innovation*, causes the number of goods produced with high sophisticated technologies to increase. The assumption is that producing a new good requires higher flexibility, higher problem solving capabilities and more creativity: in short, higher skills on behalf of the worker.

An expansion of the range of goods that can be produced with low skilled labour is labelled *process innovation*. One could think of technical change as an improvement in the interface between production technology and the worker, thus allowing a low skilled worker to perform complicated tasks, previously only manageable by high skilled workers. Not only does the interface allow low skilled workers to become productive, it also allows the high skilled workers to be more productive than before. New goods thus mature as their interface develops over time.[3] Using this framework we show two possible labour market regimes can result. In both skill biased technical change will cause a drop in the relative demand for low skilled workers.

Section 3 proceeds by analysing the response to skill biased technical change under both labour market regimes. In one regime high skilled workers are employed in the production of both classes of goods. It is labelled *incomplete specialisation*. Under this regime the drop in demand has no impact on relative wages, but causes a reallocation of labour, a reduction of skill mismatch if you will, instead. Under the alternative regime of *full specialisation* we show technical change can be the prime cause of wages diverging between skilled and unskilled workers.

Section 4 introduces wage bargaining into the model. Here we show that wage divergence can be "traded off" against increasing relative unemployment of low skilled workers under the full specialisation regime. This situation broadly corresponds to empirical evidence on wage- and unemployment developments in the Anglo-Saxon countries. Moreover, the incomplete specialisation regime breaks up in two sub-regimes when bargaining is introduced. Under these sub-regimes wages do diverge due to technical change even though there is incomplete specialisation. For very low relative wages we find a regime of full employment for both skill types. A more likely regime of relatively stable asymmetric unemployment can also occur and is consistent with the evidence on employment and wage patterns on mainland Europe.

Section 5 presents our conclusions.

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[3] This setup is reminiscent of Krugman's (1979) model of North-South Trade. The product cycle is simplified to two stages of production.

2. The Drop in Relative Low Skilled Labour Demand

General Settings

Our economy consists of two types of households. We have consumers that consume a range of goods and derive utility thereof. The utility function was taken from Krugman (1979) and has the well known "love of variety" characteristics. All consumers are assumed identical and are represented by an individual that maximises his and therefore total utility by choosing the appropriate levels of consumption for each good, subject to his budget constraint.

The variety of goods is produced by a range of production units that can only be distinguished on the basis of their technology determined input requirements. Some varieties can only be produced by high skilled labour due to the sophistication of the production process - the class of high-tech or new goods. Others are manufactured in a routine like manner and can thus be produced by employing either high or low skilled workers- these constitute the class of low-tech or mature goods. Within a class of goods the goods are perfectly symmetric both in terms of utility and production technology. There are no other inputs apart from high and low skilled labour in our model.

By assuming price taking behaviour on behalf of the consumer and monopolistic price setting by producers we find all high-tech goods have the same price, as do all low-tech goods, within their class.

The producers set prices given demand, wages and their production technology. By the symmetry and diminishing returns assumed within classes their decision is reduced to choosing an average output level for high and low-tech goods, where output per variety within a class is the same.[4] In the following subsections we first analyse the consumer decision and the producers' decisions in isolation. Then the goods market equilibrium can be derived. By confronting the labour demand that is derived from profit maximization with exogenous labour supply we can close the model and analyse the impact of skill biased technical change in comparative statics.

The Consumer Decision

Consumers maximize their utility. Assume a representative consumer whose utility is given by:

$$U=\left[\sum_{i=1}^{n} c_i^{\alpha}\right]^{1/\alpha} \qquad 0<\alpha<1 \qquad \textbf{(1)}$$

where c_i is the consumption of good i and n is the number of varieties of goods produced and $1/1-\alpha$ the elasticity of substitution between two varieties. When we distinguish between a class of goods that can be produced using high skilled labour and one in which both types of labour can be used, we may write this utility function also as:

$$U=\left[n_H c_H^{\alpha}+n_L c_L^{\alpha}\right]^{1/\alpha} \qquad \textbf{(2)}$$

[4] Here we deviate from Krugman (1979) who assumes a one-on-one technology.

where subscripts *H*(igh) and *L*(ow) indicate the level of sophistication of the technology used to produce those goods and c_H and c_L are the *average* amounts of consumption of high and low sophisticated goods, respectively.[5] Finally n_H and n_L indicate the number of varieties of both goods. We maximise the utility function subject to the simple budget constraint, $Y = P_H n_H c_H + P_L n_L c_L$, where Y is income and P_H and P_L are the price levels for both classes of goods. Then relative average consumption of high and low-tech goods is a function of the relative price:

$$\frac{c_H}{c_L} = \left[\frac{P_H}{P_L}\right]^{\frac{1}{\alpha - 1}} \qquad \textbf{(3)}$$

The Producers and Goods Market Equilibrium

Each variety is produced in a situation of profit maximisation under imperfect competition on the product markets (varieties are heterogenous by assumption) and perfect competition on the labour market. Labour (measured in efficiency units) is the only factor of production distinguished in the model.

We identify two groups of producers. As was mentioned above, the output of a variety of high sophisticated goods can only be produced by employing high skilled labour. High skilled labour not employed by the high tech producers is available for the production of low sophisticated goods as is the entire supply of low skilled labour. The output of any variety exhibits diminishing returns in the relevant input. Due to the symmetry in production within a class of products and the diminishing returns, the average output per variety is equal to the output of any variety within that class. It can be written as a function of the labour input per variety. Average output of a low sophisticated variety is given by:

$$x_L = [l^e_L]^{\beta} \qquad 0<\beta<1 \qquad \textbf{(4)}$$

Where $l^e_L = (L_L + \epsilon L_{HL})/n_L$, is the average labour input on all n_L low sophisticated varieties measured in efficiency units. L_L is the number of low skilled workers employed and L_{HL} is the number of high skilled workers on low sophisticated jobs. The latter workers are assumed to be ϵ times as efficient as low skilled workers.[6] For all n_H highly sophisticated varieties output is also equal to average output:

$$x_H = [l_{HH}]^{\beta} \qquad 0<\beta<1 \qquad \textbf{(5)}$$

Where $l_{HH} = L_{HH}/n_H$ is the amount of high skilled labour employed in the production of each

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[5] In a symmetric utility function consumers optimize by spreading consumption equally across all varieties that command the same price. Hence consumers consume the average amount of all varieties within each class and $c_H = (c_{h1} + c_{h2} + ... + c_{hnH})/n_H$.

[6] $\epsilon > 1$. Some tentative evidence in Van Zon, Muysken and Meijers (1998) has shown this value is approximately 1.25 in the Netherlands between high and medium and medium and low level skills.

high tech variety. Profits for both types of producers are given by:

$$\pi_H = P_H x_H - w_H l_{HH} \quad \textbf{(6)}$$

$$\pi_L = P_L x_L - w_L l^{e}_{L} \quad \textbf{(7)}$$

Where w_H and w_L are the wages paid to one efficiency unit of high and low skilled labour respectively. Producers now set prices to maximise profits given the relative demand for their product (3), the production function (4) and (5) and wages. Standard optimization yields the profit maximizing relative average supply as a function of relative prices and wages:

$$\frac{x_H}{x_L} = \left[\frac{w_H/P_H}{w_L/P_L}\right]^{\frac{\beta}{\beta-1}} \quad \textbf{(8)}$$

Equating relative average supply (8) and demand (3) yields the relative prices as a function of relative wages for which the goods markets clear:

$$\frac{P_H}{P_L} = \left[\frac{w_H}{w_L}\right]^{\frac{\beta-\alpha\beta}{1-\alpha\beta}} \quad \textbf{(9)}$$

Equation (9) describes the relative wage-price frontier for which the goods market is in equilibrium. Figure 1 shows this frontier, labelled *GME*, is a concave line through the origin in *P*,*w*-space, where *P* and *w* are the relative price and wage ratio respectively.

The Demand for Labour

A similar approach can be followed to derive the relative wage-price frontier for the labour market. Since labour is the only factor of production in the model, it follows that the supply of a certain type of good directly generates a corresponding demand for the appropriate type of labour.

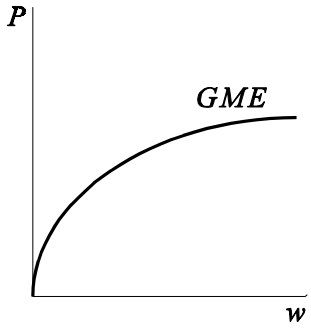


Figure 1: Goods Market Equilibrium

By substituting for output in (8) by (4) and (5), we can solve for the relative implied demand for labour (in appropriately skilled efficiency units) as a function of the relative product wages If we aggregate over all varieties we find the aggregate relative labour demand:

$$\frac{L^{D}{}_{H}}{L^{D}{}_{L^{e}}} = \frac{n_L}{n_H}\left[\frac{w_H/P_H}{w_L/P_L}\right]^{\frac{-1}{1-\beta}} \qquad \textbf{(10)}$$

The Impact of Skill Biased Technical Change on Relative Labour Demand

Now we define technical change in our model as the expansion of either range of product varieties. Increasing the total range of varieties, *n*, implies introducing new products into the economy, which we label *product innovation*. Increasing the range of low-tech products, n_L, requires the development of an interface that allows low skilled workers to perform the previously high skilled jobs. Hence we label this type of innovation *process innovation.*

Skill biased technical change can now be represented by allowing n_H $(=n-n_L)/n_L$ to rise. We immediately see from (10) that it will cause a drop in the relative demand for low skilled labour, measured in efficiency units. The economy can respond to this shock in two ways, as the next section will show. There we first close the model by specifying labour supply in order to analyse these responses.

3. Regimes and Responses in the Labour Market

In this section we introduce exogenous labour supply to provide a benchmark case and analyse the possible responses to biased technical change without allowing for different institutional settings. First we specify the supply side of the labour market, then we close the model and analyse the impact of biased technical change on the reduced form equations we obtain.

Inelastic Labour Supply and Equilibrium in the Labour Market

Total supply of high-skilled labour is L^*_H and of low-skilled labour is L^*_L. However, as we mentioned above high-skilled workers can also be employed on low-tech jobs. They will be willing to do this when high-skilled jobs do not offer a wage in excess of that which a high skilled individual earns on low-tech jobs, that is when $w_H \leq \epsilon w_L$. Actually when $w_H > \epsilon w_L$ all high-skilled labour L^*_H will be supplied to high-tech jobs, whereas when $w_H < \epsilon w_L$ all high-skilled labour will be supplied to low-tech jobs. Only when $w_H = \epsilon w_L$ are high-skilled workers indifferent where to supply their labour, and supply of high skilled labour on low skilled jobs, L_{HL}, is indeterminate in the range $0 < L_{HL} < L^*_H$.

As a consequence, relative supply in efficiency units can be written as follows:

$$\begin{aligned}
\frac{L^{S}_{HH}}{L^{S}_{Le}} &= 0 && for\ \frac{w_H}{w_L} < \epsilon \\
\frac{L^{S}_{HH}}{L^{S}_{Le}} &= \frac{L^{*}_{H} - L_{HL}}{L^{*}_{L} + \epsilon L_{HL}} && for\ \frac{w_H}{w_L} = \epsilon \\
\frac{L^{S}_{HH}}{L^{S}_{Le}} &= \frac{L^{*}_{H}}{L^{*}_{L}} && for\ \frac{w_H}{w_L} > \epsilon
\end{aligned} \qquad \textbf{(11)}$$

Equating (10) and (11) yields the relative wage-price frontier for which the labour market is in equilibrium:

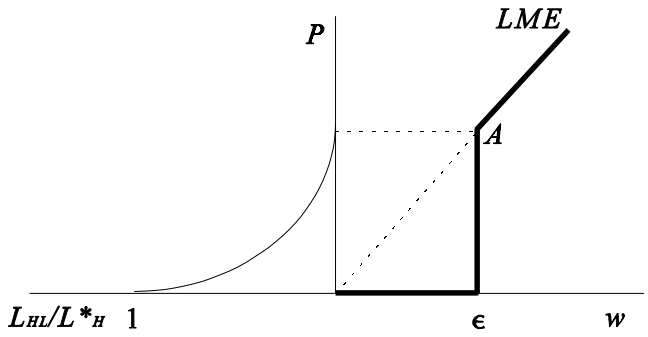
$$\begin{aligned}
\frac{P_H}{P_L} &= 0 && for\ \frac{w_H}{w_L} < \epsilon \\
\frac{P_H}{P_L} &= \frac{w_H}{w_L}\left[\frac{(L^{*}_{H} - L_{HL})/n_H}{(L^{*}_{L} + \epsilon L_{HL})/n_L}\right]^{1-\beta} && for\ \frac{w_H}{w_L} = \epsilon \\
\frac{P_H}{P_L} &= \frac{w_H}{w_L}\left[\frac{L^{*}_{H}/n_H}{L^{*}_{L}/n_L}\right]^{1-\beta} && for\ \frac{w_H}{w_L} > \epsilon
\end{aligned} \qquad \textbf{(12)}$$

It can be verified in equation (12) that producers will set relative prices proportional to relative wages with a factor of proportion that depends on the relative availability of high skilled workers and the relative size of the high skilled sector.

The labour market equilibrium represented by equation (12) can be represented in *w*,*P*-space as well - the Labour Market Equilibrium curve, *LME*, in Figure 2. For $w_H < \epsilon w_L$ it coincides with the horizontal axis, whereas for $w_H > \epsilon w_L$ it traces out a linear upward sloping line on which the labour market is in equilibrium. Finally, for $w_H = \epsilon w_L$ the curve is vertical.[7]

[7] As we have mentioned above, L_{HL} refers to the supply of high-skilled workers on low skilled jobs. It can be shown from the first order conditions for low skilled producers that these workers will only be employed on these jobs when relative wages match relative efficiency, that is $L_{HL}>0$ can only occur when $w_H/w_L=\epsilon$. It is profitable to replace low skilled workers with high skilled workers on low skilled jobs as long as the latter condition is a strict inequality (<). On the other hand, high skilled wages should always exceed or equal those for low skilled jobs, that is $w_H \geq \epsilon w_L$. Otherwise all high-skilled workers will seek employment on low skilled jobs. Therefore an equilibrium with $0<L_{HL}<L^{*}_{H}$ is only possible for $w_H/w_L=\epsilon$.

Figure 2: Equilibrium in the Labour Market



For the relative wage equal to ϵ, equation (12) can be solved to yield skill mismatch, L_{HL}/L^*_H, as a function of relative prices only:

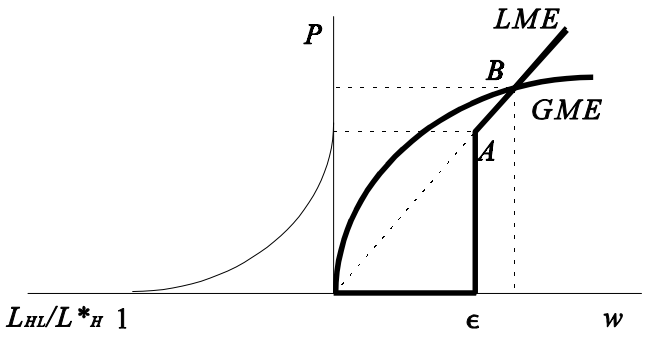
$$\frac{L_{HL}}{L^*_H} = \frac{\frac{L^*_H/n_H}{L^*_L/n_L} - \left[\frac{P_H}{P_L}\right]^{\frac{1}{1-\beta}} \epsilon^{\frac{1}{\beta-1}}}{\epsilon^{\frac{\beta}{\beta-1}} \left[\frac{P_H}{P_L}\right]^{\frac{1}{1-\beta}} + \frac{L^*_H/n_H}{L^*_L/n_L}} \qquad \textbf{(13)}$$

It can be verified in (13) this relationship is negative in relative prices. This is plausible since as relative prices increase, the high-tech sector can increase profits by employing more high skilled workers at the given relative wages and thus reduce mismatch. The left quadrant in Figure 2 shows this relationship as a downward sloping curve with a positive intercept at the relative price level where demand for high skilled labour at $w_H/w_L = \epsilon$ will equal total supply.

The Equilibrium with Inelastic Labour Supply

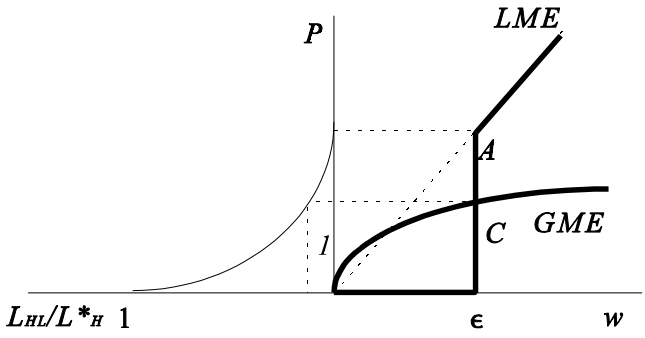
In order to determine the simultaneous equilibrium of our model Figures 3 and 4 combine the goods and labour market equilibrium wage-price frontiers. As the *GME* is a concave line in *w,P*- space and the *LME* is upward sloping and linear from $w_H/w_L = \epsilon$ onwards, we know there is a unique point of intersection for $w_H > \epsilon w_L$. This is shown in Figure 3.

Figure 3: The *Complete Specialisation* Equilibrium



In such an equilibrium the wages paid in the high skilled sector are too high for low tech producers to benefit from their employment. This implies they will set $L_{HL} = 0$ and relative wages now adjust to bring about equilibrium. The economy would remain in a point such as *B* and the left quadrant shows the employment rate of high skilled workers in the low tech sector is 0. Hence we label this equilibrium *complete specialisation*.

Figure 4: The *Incomplete Specialisation* Equilibrium



Another possible equilibrium is illustrated in Figure 4 and prevails when the *GME*-curve intersects with the *LME*-curve below point *A*. In such an equilibrium low tech producers find it attractive to employ high skilled workers. And in the process of competing for high skilled workers they will drive up the relative wages until $w = \epsilon$. The economy reaches an equilibrium at point *C*, where the *GME*-curve intersects with $w = \epsilon$. In such an equilibrium there is positive skill mismatch L^*_{HL} as can be seen from the left panel of Figure 4. We label this equilibrium *incomplete specialisation*.[8]

It can be seen from equations (9) and (12), the *GME*-curve does not change when labour supply or the number of varieties change, whereas the *LME*-curve does. That is, the *LME*-curve rotates clockwise both when L_H^*/L_L^* and n_L/n_H decrease. This implies that when low skilled labour is abundant, the ratio of high wages relative to low wages will be high and no high skilled labour will be employed on low tech jobs. It can easily be shown that complete specialisation will occur when:

$$\frac{n_H}{n_L} > \epsilon^{\frac{1}{1-\alpha\beta}} \frac{L^*_H}{L^*_L} \qquad \textbf{(14)}$$

As one might expect, the tendency towards full specialisation will be reinforced by product innovations that increase n_H. For such innovations increase the relative scarcity of high skilled labour. Process innovations can be shown to have exactly the opposite effects

The Response to Technical Change

We now turn to the issue of different responses to a common shock. As we observed skill

[8] From equation (9) one can see that incomplete specialisation is characterised by relative prices that exceed unity, i.e. high-tech goods are more expensive than low-tech goods. It is obvious that this also holds for complete specialisation.

biased technical change in the form of product innovations cause a drop in the relative demand for low skilled labour in efficiency units. The response to such a shock is determined by the size of the shock and the regime we assume the economy to be in at the time of the shock. In the beginning of the 80s there was, as we stated in the introduction, a positive level of skill mismatch, indicating a regime of incomplete specialisation. The economy would find itself at the intersection of *LME* and *GME* in a point such as *B*. Under that regime our model predicts an increase in n_H/n_L , our representation of skill biased technical change, will cause a reduction of skill mismatch and stable relative wages. This is illustrated in figure 8. As n_H/n_L

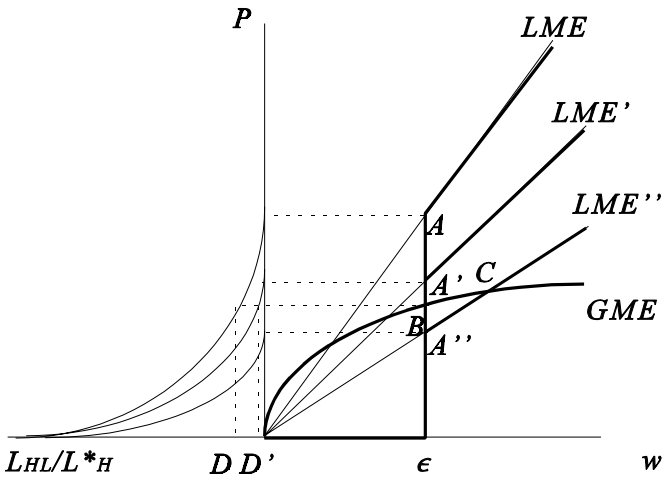


Figure 8: Three Scenario's in Response to Product Innovation

increases it can be verified in equation (12) that the *LME* will rotate clockwise around the origin and point *A* moves down to *A*'. The relative wage stays at ϵ and skill mismatch is reduced from *D* to *D*'. Both correspond to the stylized facts we mentioned for Europe in table 1.

In the US and most Anglo-Saxon countries skill mismatch is a non-issue in the economic literature so we concluded it is not a significant problem in these countries. This would imply the Anglo-Saxon world was in or very close to a regime of complete specialisation in the early 80s and found itself at the intersection of *LME*' or *LME*" and the *GME*-curve. Under that regime our model predicts skill mismatch will fall to zero and any further increase in n_H/n_L will cause strong wage divergence as we observed has occurred in these parts of the OECD.

To explain the stylized facts regarding relative and absolute unemployment rates we obviously have to extend the model and allow for labour supply to respond to changes in wages.

4. Wage Formation and Unemployment

So far we have not allowed labour supply to respond to wage adjustments and have assumed zero unemployment. Unemployment will now be introduced in the analysis by assuming endogenous labour supply and repeating the analysis outlined above.

Wage Formation and Labour Market Equilibrium with Elastic Labour Supply

When we endogenise labour supply and allow for unemployment, the results will obviously change, although not qualitatively. We will, for the purpose of this paper, abstract from microeconomic foundations underlying our labour supply conditions. For now we refer the reader to for example Layard, Nickell and Jackman (1994) and put the exact derivation of our assumptions on the agenda for further research.

Here we assume a process of wage bargaining, both by high-skilled workers and by low-skilled workers, taking each other's wage as a reference, in the context of a right-to-manage model.[9]

High skilled workers will negotiate a wage, w_H, for the high tech sector. They will take demand for high skilled employment in that sector, L_{HH}, into account and use as an outside option, the wage a high skilled worker can earn in the low tech sector, $w_{HL} = \epsilon w_L$. The difference between exogenous total high skilled labour supply, L_H^*, and the level of employment in the high tech sector is labelled excess high skilled labour supply, L^s_{HL}, which will turn to the low skilled sector. We thus define $L^s_{HL} = L_H^* - L_{HH}$. In the case that w_H would be below ϵw_L , all high skilled labour supply would turn to the low tech sector.

We assume for simplicity that for high-skilled workers unemployment benefits are equal to the wage that would have been earned when working in the low-skilled sector, minus benefits from leisure. Therefore being unemployed is a similar threat in the bargaining process when compared to mismatch.

The high skilled wages bargained in the high tech sector are given by:

$$w_H = \gamma w_{HL}\left[\frac{1-u_{HH}}{1-u^*}\right]^{\psi} \quad 0<\psi<1 \quad \gamma>1 \quad w_H \geq w_{HL} \qquad \textbf{(15)}$$

where $u_{HH}=(L_H^*-L_{HH})/L_H^*$ is the mismatch rate of high skilled workers and u^* is the exogenous rate that high-skilled workers accept when their demands are met. The wage claim is a positive function of the level of employment of high skilled workers on high skilled jobs, expressing their willingness to accept lower wages when mismatch is reduced. Furthermore high skilled workers are assumed to take a fixed mark up, $\gamma>1$, over their outside option as a base wage. This mark up is required for example to cover costs of education. Finally, as we mentioned above, when w_H would be below w_{HL} , all high skilled labour supply would turn to the low tech sector.

Low skilled workers are assumed to take the productivity adjusted high skilled wage, w_H/ϵ, as their ultimate target and will bargain for a fraction, $1/\gamma < 1$, of that target. Since low-skilled workers are concerned about the possibility of unemployment, the bargained low skilled wage

[9] In Annex A we present the derivation of such a bargaining process that yields results very similar to those arrived at here.

is a positive function of the level of low skilled employment relative to the reference level. Moreover, low-skilled workers should take excess high-skilled labour supply L^s_{HL} into account, when considering unemployment prospects. The reason is that employers are indifferent between employing low- and high-skilled workers (in terms of efficiency units) on low-skilled jobs - cf. equation (4) above.[10]

Hence the bargained low-skilled wage is determined by:[11]

$$w_L = \frac{1}{\gamma}\frac{w_H}{\epsilon}\left[\frac{1-u_L}{1-u^*}\right]^{\psi} \qquad \textbf{(16)}$$

where $u_L = (L_L^*-L_L)/L_L^*$ is the low skilled unemployment rate - which is equal to the unemployment rate of effective labour supply on low-tech jobs[12] - and u^* represents the exogenous reference unemployment rate that low skilled workers accept when their demands are met. This equation expresses the trade off between additional unemployment and higher relative wages low skilled workers are willing to make.

Rewriting (15) and (16) into labour supply equations and confronting these with (10) yields a labour market equilibrium curve as in the previous section. Annex B provides the interested reader with the full mathematical derivation of this *LME*-curve.

Since labour supply is constrained between 0 and the exogenously given quantities of labour, L^*_H and L^*_L this *LME*-curve is kinked. Because the supply constraints become binding at particular relative wage rates for both L^s_{HH} and L^s_L , three distinct situations exist in the labour market.[13] Figure 5 shows the implications for L^s_{HH}, L^s_{HL} and L^s_L in these situations.

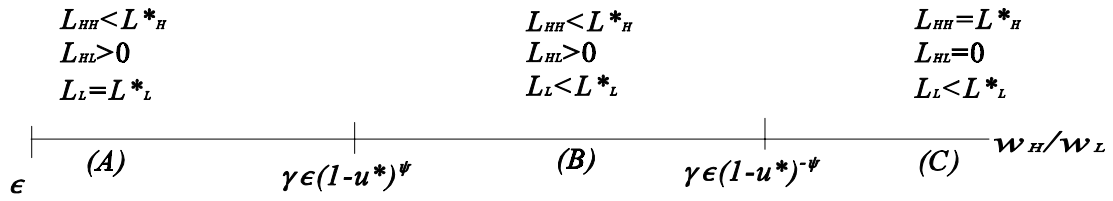


Figure 5: Various Labour Supply Conditions

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[10] Actually equation (4) does not preclude that for other reasons employers prefer to employ high-skilled workers first. In that case we would have complete crowding out of low-skilled workers.

[11] Taking the same parameters u^*, γ and ψ for both bargaining processes is just for convenience and does not alter the qualitative results.

[12] We assume therefore, since employers are indifferent between employing high or low skilled workers on low skilled jobs, that $u_L = u_{HL} = u_L^e$. Alternatively one could assume $u_{HL}=0$ which yields the complete bumping down referred to in footnote 6.

[13] We argued above that when $w < \epsilon$ all high skilled workers would seek employment in the low-tech sector. For regime *A* to be relevant, we assume $\gamma(1-u^*)^{\psi} > 1$. Actually when $w < \epsilon$ we have $L^s_{HH} = 0$, $L^s_{HL} = L^*_H$ and $L^s_L = L^*_L$. Since this can never be an equilibrium given the love-of-variety nature of the utility function, we do not present this in Figure 5.

One sees that in regime *A* when the relative wage is low - *i.e.* the low-skilled wage is high - all available low-skilled workers will supply labour. But high-skilled labour supply will be restricted in order to push for higher relative wages. As a consequence high-skilled workers will be underemployed. We label this regime *full employment incomplete specialisation.* On the other hand in regime *C* the relative wage is high and hence the high-skilled wage is high. In that case all available high-skilled workers will supply labour in the high tech sector. But low-skilled labour supply will be restricted in order to push for lower relative wages - *i.e.* higher low-skilled wages. Hence low-skilled unemployment will prevail here. This is the case of *unemployment complete specialisation*. Finally in regime *B* the relative wage will be in an intermediate range. Neither high-skilled nor low-skilled workers will be fully satisfied, hence both types of labour will be partly unemployed and high skilled labour is partly mismatched. We label this regime *unemployment incomplete specialisation.*

Whereas the *LME*-curve was a straight line in the case of full employment, it now is an upward sloping convex curve, as illustrated in Figure 6. Again we refer the reader to the annex for the mathematical derivation of this result. Moreover, because we have dropped the

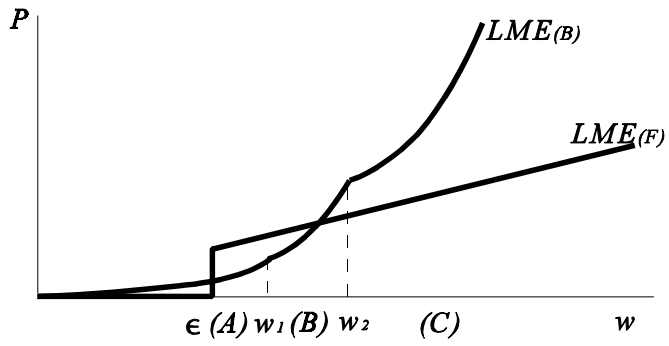

Figure 6: Labour Market Equilibrium with Endogenous Supply

assumption of indifference with regard to job type on behalf of the workers, w_{HL} is no longer necessarily equal to w_H .This also explains the convexity of the *LME*-curve.[14]
Finally, due to the different regimes elaborated in Figure 5, the curve has some breakpoints that are marked by dashed lines.[15] For comparison we have added the full employment *LME* (labelled $LME_{(F)}$).

It is interesting to note the difference that results from wage bargaining. As we discussed using equation (11), in full-employment at a wage of $w_H = \epsilon w_L$ high-skilled workers are indifferent between supplying labour to the high-tech and the low-tech sectors. Therefore essentially, the allocation of employment is determined on the goods market in that case, that is by relative prices for goods - compare Figure 4. However, from equation (14) one sees that in the case of wage bargaining, the wage $w_H = \epsilon w_L$ requires a specific level of high skilled supply $L^S_{HH} = (1/\gamma)^{1/\psi}(1-u^*)L^*_H$. Hence in the context of wage bargaining, supply is no longer undetermined. As a consequence the *LME* curve no longer is vertical at $w_H = \epsilon w_L$. At that relative wage the relative price $P(\epsilon)$ can be found by substituting $w_H = \epsilon w_L$ in the *LME*-curve.

[14] In Annex B we also show that the *LME* curve is increasing over its whole range. Moreover, the *LME*-curve is convex over the range *A*-*B*, but not including *C*. However, it is convex within the range C. Since the *GME*-curve is concave over its whole range, multiple equilibria are excluded.

[15] This is elaborated upon in Annex B

For any relative price below $P(\epsilon)$ equilibrium is not possible. Therefore equilibrium will only exist when the relative price resulting from the *GME*-curve at $w_H = \epsilon w_L$ is at least $P(\epsilon)$. We assume this to be the case.[16]

Equilibrium with Unemployment

In Figure 7 (a) we have combined Figures 1 and 6 to show the equilibria in the three regimes.[17] When the intersection of *GME* and *LME* lies in interval *(A)* we have a full employment equilibrium with positive mismatch. In interval (*B*) we have unemployment of

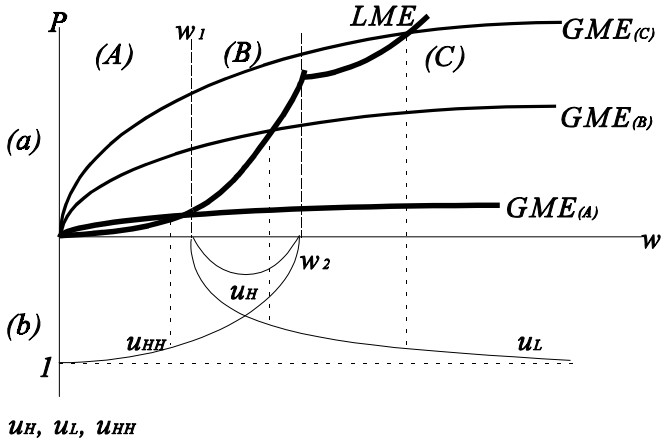

Figure 7: Possible Equilibria under Bargaining

low skilled workers and also for high skilled workers that seek employment on a low skilled job.[18] In interval (*C*) we end up in a complete specialisation equilibrium with unemployment of low skilled workers only. Panel (b) in Figure 7 shows the unemployment rates in relation to the relative wage, i.e. u_L from (15) and u_H (= u_L u_{HH}) and the mismatch rate u_{HH} from (14). The regime that prevails and it's corresponding unemployment situation is a function of the parameters of our model and therefore of the composition of our economy. From Figure 7 one sees that wages diverge when the economy moves towards complete specialisation (*C*). Beyond a particular critical wage rate (at which the full employment and bargaining *LME*-curves intersect) the convexity of the *LME*-curve, however, ensures that wages do not diverge as much under bargaining as in the model with exogenous labour supply - compare Figure 6. Unemployment starts to acts as a buffer against wage divergence.

Hence we may conclude unemployment rates can indeed be traded off against wage inequality under this specification. It depends on the parameters of the model where most of

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[16] The assumption necessary for this to hold is derived in Annex B.

[17] To keep the graph simple we have varied only the *GME*-curve. Strictly speaking this also implies a different *LME*-curve of the same shape since the *GME* depends only parameters α and β, which also have an impact on the shape of the *LME*-curve. An alternative way of showing the intersection may lie in each section would be to rotate the *LME*-curve clockwise to reflect different n_H/n_L, an exogenous variable that affects the *LME*-curve only.

[18] If we set $u^*=0$ this interval reduces to a point and thus drops out. Of course so does the corresponding regime.

the adjustment to equilibrium arises. In the next paragraphs we will turn to the comparative statics of the extended model and analyse the possible labour market responses to exogenous technical change under bargaining linking the predictions of our model to the stylized facts regarding unemployment we have presented in the introduction..

Responses to Technical Change under Bargaining

To see how the model responds to biased technical change under the endogenous labour supply specification, we can again start by analysing the impact of changes in n_H / n_L on the shape and slope of the *LME*-curve. From equation (9) we already know the *GME*-curve does not respond to changes in n_H. The impact of product and process innovations on the *LME*-curve is the same under all three regimes and also identical to the impact under exogenous labour supply. It reduces the relative price level for which the labour market clears for each relative wage rate. This can again be visualised by a clockwise rotation of the *LME*-curve around the origin while maintaining all characteristics established in Annex B. The continuity and positive slope are unaffected, but the slope becomes smaller for all relative wages as does the convexity (n_H / n_L is in the first and second derivative of the *LME* with respect to wages with a negative power). Thus the *LME*-curve rotates and starting from any equilibrium we see the relative wage rate must increase - compare Figure 7. A limited rotation of the *LME* does not provoke a regime switch but still moves the equilibrium to the right and up, implying wage divergence and a relative price increase. A larger rotation moves us from a regime of full employment incomplete specialisation into a regime of unemployment incomplete specialisation and relative unemployment rates start to diverge too. Rotating even further implies we eventually end up in a regime of unemployment complete specialisation. Here the relative unemployment rate for the low skilled is infinite and mismatch has disappeared. Wages have also diverged. However, if we compare these results to those obtained under exogenous labour supply we can conclude that wages have diverged less and unemployment is higher - compare Figure 6. The lower divergence in wages stems from the fact that the *LME* is now convex and since technical change affects the slope of the *LME*-curve in the same way as under exogenous supply the rotation is equal for the same change in n_H. This implies the new intersection with the *GME*-line must lie more to the left than under exogenous supply. This yields the intuitive result that, as in standard wage bargaining models, unemployment can be traded off against wages.

5. Summary and Concluding Remarks

To conclude our analysis we return to the stylized facts in Table 1 and compare them to the prediction our model is able to produce. We have introduced in this paper the notion that skill biased technical change in the form of an increased relative rate of product innovation is the common cause for the drop in relative low skilled labour demand throughout the OECD. Let us now first shortly summarize all possible responses our model can generate in Table 2.

Table 2: The Impact of Biased Technical Change; An increase in n_H/n_L

Initial Regime	**Flexible Wages**		**Bargaining**		
	Incomplete Specialisation	Complete Specialisation	Incomplete Specialisation		Complete Specialisation
	Full Employment		Full Employment (A)	Un-employment (B)	Un-employment (C)
w_H/w_L	(0)	(+++)	(++)	(+)	(++)
u_{HH}	(---)	(0)	(-)	(--)	(0)
u_H	n.a.	n.a.	(0)	(?)	(0)
u_L	n.a.	n.a.	(0)	(++)	(+)
u_H/u_L	n.a.	n.a.	(0)	(++)	(+)

Our bargained wages model is best equipped to address the issue of different responses to a common biased technology shock, since it allows us to address both unemployment and wage developments. It distinguishes three possible equilibria. Under the incomplete specialisation regimes we see positive skill mismatch that is reduced when product innovations are introduced. Relative wages diverge and relative unemployment, if positive, does so to. If we assume bargaining power to be high, the trade off between asymmetric unemployment and wage inequality causes a higher overall level of unemployment and a larger part of the adjustment to biased technical change falls on unemployment.

We also see that the reduction in mismatch may be accompanied by a positive and rising or declining unemployment rate for the high skilled in interval *B*, which is wider for larger "acceptable" unemployment rates *u**.

This corresponds nicely with stylized facts in mainland Europe, where skill mismatch seems to be on the retreat and relative wages do not show strong divergence, but on the other hand we see high and persistent unemployment particularly for low skilled workers and relative unemployment rates show strong divergence over the past decade.

A possible explanation for the fact that Europe is in a regime of unemployment incomplete specialisation (*B*) is the high minimum wages for low skilled labour and the policies to moderate high skilled wages. Although not explicitly analysed in this paper, such policies would push high skilled workers into the low skilled jobs. Our model does predict, however, that this stability of relative wages and unemployment will not last as the skill intensive high-tech sector expands.

Under complete specialisation our model predicts that increases in the range of skill intensive goods will cause wage divergence and moderate divergence of unemployment rates. Mismatch is absent in this regime. This situation applies to the United States, the United Kingdom and most countries in the British Commonwealth. In these countries mismatch is apparently not considered a big problem since hardly any attention is devoted to it in economic literature. Wage divergence and real wage decreases for low skilled workers, however, are deemed all the more important and Nickell and Bell (1995) show biases in labour demand account for a large part of the asymmetry in unemployment in these countries counter to what Krugman's analysis would predict. Assuming, as would seem reasonable, that labour markets are more flexible in the Anglo-Saxon world only strengthens our results.

Under complete specialisation wage divergence for any given expansion of the skill intensive sector yields higher wage divergence and lower unemployment rates for both skill types. Our model would predict that as long as the knowledge intensive sector expands relative to the rest of the economy these problems will become worse.

It remains to be established, however, what drives the process of technological change. Empirical research does not give a clear indication of whether the current problems are the result of a transitional phase to a new steady state composition of the economy in which relative wages, unemployment and mismatch again stabilize. These problems may also indicate a new and lasting trend of deteriorating employment opportunities for the low skilled. This makes further research into the process of technological change an important task.

In this paper we have presented a model that generates three possible equilibria. Using the characteristics of these equilibria we can identify the regime of unemployment incomplete specialisation with mainland Europe whereas the Anglo-Saxon world seems to be completely specialised. This implies that both will respond differently to similar technological shocks even under the same institutional settings. Allowing for differences in institutions brings us even closer to the stylized facts of wage development and unemployment, we set out to explain.

A surge in the development of new products, that remains to be shown over the last decades but can certainly not be dismissed beforehand, can explain wage divergence and increasing asymmetries in unemployment in the Anglo-Saxon world whereas it also causes a decrease in skill mismatch in mainland Europe. We do acknowledge there are many more differences between and within these area's of the OECD and do not intend to explain all of the differences in labour market performance solely from this point of view. We do, however, contend that biased technical change can be a common cause without leading to the same effects.

Furthermore our analysis sheds a different light on the policies implemented in the area's distinguished above. Relying on the so called chimney-effect to improve labour market perspectives for low skilled workers in Europe will be self-defeating as complete specialisation eventually is achieved. The undesirable side effects of such a regime are to be considered in formulating such policies. Nevertheless it is desirable to use the chimney up to the point where it stops working, since this increases welfare and wages for all workers. The often advocated policies of wage moderation do improve the relative position of low skilled workers but imply welfare losses due to inefficient allocation of skills.

As to the US policy of promoting technical change and R&D to create jobs for the unskilled by boosting international competitiveness, this may actually backfire. Promoting R&D in general may increase the development and introduction of new products and cause an

aggravation of the problem. Technology policy cannot, however, be evaluated without introducing an explicit R&D sector into the model. We therefore put this at the top of our research agenda. For now we suffice by concluding such R&D policies should be targeted in order to deal with the problem of asymmetric unemployment and wage divergence.

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Annex A: *A Labour Market Equilibrium with Bargaining*

The aim of this Annex is to present a wage formation process which is different from the process presented in the text above, but none-the-less yields a *LME*-curve with similar properties. This intends to illustrate the rather general nature of our analysis.

Assume that both high and low skilled wages are set by unions in a context of a right-to-manage model That is, wages are set such that the utility of the union is maximized given the implications for demand for labour- cf. equation (10).

The union that represents high skilled workers is assumed to desire the highest possible wage for it's members, but this wage must always exceed the low skilled wage by some factor $\gamma>1$ to compensate for the costs of acquiring the higher skills. Hence $w=w_H/w_L>\gamma$, should hold at all times.[19] Moreover, high skilled employment is valued with an intensity ξ relative to wages and we assume, some minimum acceptable level of employment, defined as a share δ of the "natural"employment level $(1-u^*)L_H^*$. The union utility function is thus given by:

$$U_H=w_L[w-\gamma]\left[L_{HH}-\delta[1-u*]L^{*}_{H}\right]^{\xi} \qquad \textbf{(A1)}$$

The equilibrium demand for labour can be expressed as a function of relative wages by combining (9) and (10), which yields:

$$L^{D}_{H}=n_H l_{Le} w^{-\frac{1}{1-\alpha\beta}} \qquad \textbf{(A2)}$$

The union is assumed to take the average employment level in the other sector, l_{Le}, as given. Hence maximising utility with respect to relative wages subject to the demand for labour in equation (A2) yields:[20]

$$L_{HH}=\frac{\delta[1-u*]}{1-\frac{\xi[1-\gamma/w]}{1-\alpha\beta}}L^{*}_{H} \qquad \textbf{(A3)}$$

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[19] For simplicity we assume that unemployment benefits are equal to the wage that would have been earned when working, minus benefits from leisure. Therefore being unemployed is not a threat in the bargaining process.

[20] Equation (A3) can also be written as:

$$w=\gamma\xi/\left[\xi-[1-\alpha\beta]\left[1-\delta\frac{1-u*}{1-u_{HH}}\right]\right]$$

which is very similar to (15).

Preferences for the union representing the low skilled workers similarly express a desire for a highest possible wage, which must exceed their outside option, the unemployment benefit, w_u, by at least a factor γ to compensate them for the leisure lost.[21] Hence $w_L - \gamma w_u > 0$ at all times. Assuming unemployment benefits are a constant fraction ζ of low skilled wages, substituting for unemployment benefits and multiplying and dividing by the high skilled wage yields the excess of low skilled wages over their minimum acceptable wage as $w_H(1-\gamma\zeta)w^{-1}$. Like in the case of the union for high skilled labour we assume the union for low skilled labour also cares for employment.[22] Moreover we assume for simplicity employment enters the union utility function in the same way as for the high skilled workers union:

$$U_L = w_H[1-\gamma\zeta]w^{-1}\left[L_L - \delta[1-u*]L^*_L\right]^{\xi} \qquad \textbf{(A4)}$$

Again we find the equilibrium demand for labour from combining (9) and (10):

$$L^D_{Le} = n_L l_{HH} w^{\frac{1}{1-\alpha\beta}} \qquad \textbf{(A5)}$$

Since the low skilled union takes the level of high skilled wages and average high skilled employment as exogenous, maximising the utility function with respect to relative wages given labour demand yields:

$$L^S_L = \frac{\delta[1-u*]}{1-\frac{\xi}{1-\alpha\beta}} L^*_L \qquad \textbf{(A6)}$$

Finally we assume that in equilibrium $L_{Le} = L_L + \epsilon L_{HL}$ holds, hence employers in the low skilled sector are assumed to be indifferent between high or low skilled labour, measured in efficiency units. Combining equations (A3) and (A6) yields the relative aggregate supply of labour:

$$\frac{L_{HH}}{L_{Le}} = \frac{\frac{\delta[1-u*]}{1-\alpha\beta-\xi[1-\gamma/w]} L^*_H}{\frac{\delta[1-u*]}{1-\alpha\beta-\xi} L^*_L + \epsilon[1-\alpha\beta]L_{HL}} \qquad \textbf{(A7)}$$

[21] Taking the parameters $u*$, γ and ψ for both bargaining processes is just for convenience and does not alter the qualitative results.

[22] However, the low-skilled workers ignore the potential presence of high-skilled workers on low skilled jobs.

Confronting this expression with the aggregate version of (10):

$$\frac{L_{HH}}{L_{L^e}} = \frac{n_H}{n_L}\left[\frac{w}{P}\right]^{\frac{1}{\beta-1}} \qquad \textbf{(A8)}$$

yields the *LME*-curve:

$$P = w\left[\frac{n_L}{n_H}\right]^{1-\beta}\left[\frac{\frac{\delta[1-u^*]}{1-\alpha\beta-\xi[1-\gamma/w]}L^*_H}{\frac{\delta[1-u^*]}{1-\alpha\beta-\xi}L^*_L + \epsilon[1-\alpha\beta]L_{HL}}\right]^{1-\beta} \qquad \textbf{(A9)}$$

It can be shown that *LME*-curve essentially has the same properties as the *LME*-curve in (B5). Both the first and second derivative with respect to *w* are positive under our parameter restrictions, implying the *LME*-curve is upward sloping and convex in *P,w*-space as is shown to hold as well for our *LME*-curve in Annex B. The analysis then can be pursued along the text.

Annex B: *Derivation and Properties of the LME- curve with Endogenous Labour Supply*

The wage equations (15) and (16) can be rewritten to give the following (kinked) labour supply equations. For high-skilled labour we find from equation (15):

$$\begin{aligned} L^{s}_{HH} &= 0 && \frac{w_H}{w_L} < \epsilon \\ L^{s}_{HH} &= \left[\frac{w_H}{\gamma \epsilon w_L}\right]^{\frac{1}{\psi}} \left[1-u^{*}\right] L^{*}_{H} && \epsilon \leq \frac{w_H}{w_L} \leq \gamma \epsilon (1-u*)^{-\psi} \\ L^{s}_{HH} &= L^{*}_{H} && \frac{w_H}{w_L} > \gamma \epsilon (1-u*)^{-\psi} \end{aligned} \qquad \textbf{(B1)}$$

where the latter kink follows from the observation that supply cannot exceed L_H*. The first kink follows from the observation above, that when w_H would be below w_{HL} , all high skilled labour supply would turn to the low tech sector.

As we explained above, excess supply of high-skilled labour will spill over to the low-tech sector, such that $L^{s}_{HL} = L^{*}_{H} - L^{s}_{HH}$ holds. Thus we find:

$$\begin{aligned} L^{s}_{HL} &= L^{*}_{H} && \frac{w_H}{w_L} < \epsilon \\ L^{s}_{HL} &= L^{*}_{H} - L^{s}_{HH} && \epsilon \leq \frac{w_H}{w_L} \leq \gamma \epsilon (1-u*)^{-\psi} \\ L^{s}_{HL} &= 0 && \frac{w_H}{w_L} > \gamma \epsilon (1-u*)^{-\psi} \end{aligned} \qquad \textbf{(B2)}$$

In an analogous way we find the equation for low-skilled labour supply, although here we should take effective labour supply into account. This implies:

$$\begin{aligned} L^{s}_{Le} &= \left[\frac{w_H}{\gamma \epsilon w_L}\right]^{-\frac{1}{\psi}} \left[1-u^{*}\right] \left[L^{*}_{L} + \epsilon L^{S}_{HL}\right] && \frac{w_H}{w_L} \geq \gamma \epsilon (1-u*)^{\psi} \\ L^{s}_{Le} &= L^{*}_{L} + \epsilon L^{S}_{HL} && \textit{otherwise} \end{aligned} \qquad \textbf{(B3)}$$

Using the supply functions and the condition that all non-employed high skilled workers supply their labour in the low skilled labour market we can derive for each case a relative supply:

$$\frac{l^{S}{}_{HH}^{(A)}}{l^{S}{}_{Le}} = \frac{n_L}{n_H} \quad \frac{\left[\frac{1}{\gamma\epsilon}\frac{w_H}{w_L}\right]^{\frac{1}{\psi}}\left[1-u^{*}\right]L^{*}{}_{H}}{L^{*}{}_{L}+\epsilon L^{*}{}_{H}-\left[\frac{1}{\gamma\epsilon}\frac{w_H}{w_L}\right]^{\frac{1}{\psi}}\left[1-u^{*}\right]\epsilon L^{*}{}_{H}}$$

$$\frac{l^{S}{}_{HH}^{(B)}}{l^{S}{}_{Le}} = \frac{n_L}{n_H} \quad \frac{\left[\frac{1}{\gamma\epsilon}\frac{w_H}{w_L}\right]^{\frac{1}{\psi}} L^{*}{}_{H}}{\left[\frac{1}{\gamma\epsilon}\frac{w_H}{w_L}\right]^{\frac{1}{\psi}}\left[L^{*}{}_{L}+\epsilon L^{*}{}_{H}\right]-\left[1-u^{*}\right]\epsilon L^{*}{}_{H}} \qquad \textbf{(B4)}$$

$$\frac{l^{S}{}_{HH}^{(C)}}{l^{S}{}_{Le}} = \frac{n_L}{n_H} \quad \frac{L^{*}{}_{H}}{\left[\frac{1}{\gamma\epsilon}\frac{w_H}{w_L}\right]^{\frac{1}{\psi}}\left[1-u^{*}\right]L^{*}{}_{L}}$$

These are the endogenous relative supply versions of equation (11). Confronting them with total labour demand as in equation (10) we find the relation between relative prices and relative wages for which the labour market is in equilibrium. The resulting *LME*-curve is kinked at the relative wage rates for which either supply constraint becomes or ceases to be binding. The general form for the *LME*-curve is:

$$\frac{P_H}{P_L} = \frac{w_H}{w_L}\left[\frac{l^{S}{}_{HH}^{(A)}}{l^{S}{}_{Le}}\right]^{1-\beta} \qquad \epsilon \le \frac{w_H}{w_L} < \gamma\epsilon(1-u*)^{\psi}$$

$$\frac{P_H}{P_L} = \frac{w_H}{w_L}\left[\frac{l^{S}{}_{HH}^{(B)}}{l^{S}{}_{Le}}\right]^{1-\beta} \qquad \gamma\epsilon(1-u*)^{\psi} \le \frac{w_H}{w_L} \le \gamma\epsilon(1-u*)^{-\psi} \qquad \textbf{(B5)}$$

$$\frac{P_H}{P_L} = \frac{w_H}{w_L}\left[\frac{l^{S}{}_{HH}^{(C)}}{l^{S}{}_{Le}}\right]^{1-\beta} \qquad \frac{w_H}{w_L} > \gamma\epsilon(1-u*)^{-\psi}$$

Conditions for the Existence of a Unique Equilibrium

For a unique equilibrium to exist we require the *GME*-curve to intersect the *LME*-curve at a price level that exceeds $P_{LME}(\epsilon)$. $P_{LME}(\epsilon)$ follows setting $w_H/w_L=\epsilon$ in (B5) which yields:

$$P_{LME}(\epsilon) = \epsilon\left[\frac{n_L}{n_H}\right]^{1-\beta}\left[\frac{L^{*}{}_{L}+\epsilon L^{*}{}_{H}}{\left[\frac{1}{\gamma}\right]^{\frac{1}{\psi}}\left[1-u^{*}\right]L^{*}{}_{H}}-\epsilon\right]^{\beta-1} \qquad \textbf{(B6)}$$

Setting $w_H/w_L=\epsilon$ in the *GME*-curve (9) yields: $P_{GME}(\epsilon) = \epsilon^{(\beta-\alpha\beta)/(1-\alpha\beta)}$. By assuming $P_{GME}(\epsilon) \geq P_{LME}(\epsilon)$ we can guarantee an equilibrium exists.

Properties of the LME-curve

Let $L^s_{HH}/L^{s\,e}_{L} = f(x)$, where $x = (w/\gamma\epsilon)^{1/\psi}$, and $w = w_H/w_L$ is the relative wage. This implies for cases A - C:

$$A(x) = \frac{x\left[1-u^*\right]L^*_H}{L^*_L+\epsilon L^*_H - x\left[1-u^*\right]\epsilon L^*_H} \qquad \textbf{(B7)}$$

$$B(x) = \frac{x\,L^*_H}{1/x\,[L^*_L+\epsilon L^*_H]-[1-u^*]\epsilon L^*_H} \qquad \textbf{(B8)}$$

and:

$$C(x) = x\,\frac{L^*_H}{\left[1-u^*\right]L^*_L} \qquad \textbf{(B9)}$$

respectively, compare equations (B4).
The *LME*-curve is given by

$$P = w\,[n\,f(x)]^{1-\beta} \qquad \textbf{(B10)}$$

where P represents relative prices and $n = n_L/n_H$, is the relative size of the low tech class of goods.
From equation (B4) it follows that the slope of the *LME* curve is given by:

$$\frac{dP}{dw} = [n\,f(x)]^{1-\beta}\left[1 + \frac{1-\beta}{\psi}\frac{xf'(x)}{f(x)}\right] \qquad \textbf{(B11)}$$

which is positive whenever $xf'(x)/f(x) > 0$. We shall show this to be the case.

With respect to the second order derivative we find:

$$\frac{d^2P}{dw^2} = (1-\beta)[n\,f(x)]^{-\beta}\left[1 + \frac{1-\beta}{\psi}\frac{xf'(x)}{f(x)} + \frac{n\,f(x)}{\psi}\frac{d}{dw}\frac{xf'(x)}{f(x)}\right] \qquad \textbf{(B12)}$$

The *LME*-curve then is concave whenever $\frac{d}{dx}\frac{xf'(x)}{f(x)} > 0$. We shall show that this holds too.

From equations (B7) - (B9) we can derive:

$$\frac{xA'(x)}{A(x)} = \frac{L^*_L + \epsilon L^*_H}{L^*_L + \epsilon L^*_H - x\left[1-u^*\right]\epsilon L^*_H}$$

$$\frac{xB'(x)}{B(x)} = 1 + \frac{L^*_L + \epsilon L^*_H}{L^*_L + \epsilon L^*_H - x\left[1-u^*\right]\epsilon L^*_H} \qquad \textbf{(B13)}$$

$$\frac{xC'(x)}{C(x)} = 1$$

Combining equation (B13) with equation (B11) shows that the *LME* curve is increasing over its whole range. Moreover, combining this equation with equation (B12) shows that the LME-curve is convex within each range. Finally since $xB'(x)/B(x) > xA'(x)/A(x) > xC'(x)/C(x)$ the *LME*-curve is convex over the range *A*-*B*, but not including *C*. However, since the *GME*-curve is concave over its whole range, multiple equilibria are excluded.